Role of parallel flow fluctuation in potential vorticity mixing and zonal flow generation in tokamak plasmas: A gyrokinetic simulation study

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When drift waves are coupled to ion acoustic waves in a three-dimensional system, zonal flow is expected to be driven by the compression of fluctuating parallel flow [1,2]. In this work, we perform gyrokinetic simulations of toroidal ITG turbulence to investigate how the parallel flow fluctuations influence the zonal flow generation. We obtain different levels of parallel flow fluctuations by varying the equilibrium parallel flow shear. Radial structures of zonal flow show clear differences in the cases with and without the equilibrium parallel flow shear.

We analyze the generation processes of zonal flow in the framework of a kinetic version of the potential vorticity (PV) mixing theory [3], where ion gyro-center density acts as the effective PV. The PV flux estimated from the flux of gyro-center density well explains the generation of zonal flow. We evaluate the contributions of the gyro-center drift motions on the PV evolution. We find that the grad-B drift of the temperature fluctuation, the parallel compression of the parallel flow fluctuation, and the $E \times B$ advection are dominant processes in order. As the parallel flow fluctuation increases with the equilibrium parallel rotation shear, the parallel compression becomes comparable to the grad-B drift. Furthermore, we evaluate the PV fluxes caused by the parallel and perpendicular dynamics, i.e. the parallel compression versus the other contributions. The parallel and perpendicular dynamics induce, respectively, inward and outward gyro-center fluxes, whose magnitude are very similar. The net PV flux is determined by their difference. In the cases without equilibrium parallel rotation shear, net outward gyro-center flux is produced since the perpendicular dynamics dominates the parallel motion. When the parallel dynamics are enhanced, it takes over the perpendicular dynamics and drives a net inward gyro-center flux, leading to a reverse of the zonal flow direction. The PV transport analysis results identify that the compression of parallel flow fluctuation is an essential element of the zonal flow generation in toroidal ITG turbulence.

References:

[1] H. Jhang, S. S. Kim, S. Tokunaga, P. H. Diamond, Proc. 24th IAEA Fusion Energy Conf. (San Diego, CA, 2012) http://www-naweb.iaea.org/napc/physics/FEC/FEC2012/papers/142_TH62.pdf

[2] Lu Wang, P. H. Diamond, T. S. Hahm, Plasma Phys. Control. Fusion **54** (2012) 095015.

[3] C. J. McDevitt, P. H. Diamond, O. D. Gurcan, T. S. Hahm, Phys. Plasmas **17** (2010) 112509.